

HIGHWAY RESEARCH AT PURDUE 1976-77

HAROLD L. MICHAEL

Associate Director

Joint Highway Research Project

INTRODUCTION

In the spring of 1936, the Indiana State Highway Commission and Purdue University authorities by agreement established the Joint Highway Research Project. On March 11, 1937, 40 years ago, the Indiana state legislature established the joint project officially by passage of an act which authorized the highway commission to fund highway research and conduct the annual Purdue Road School at Purdue University.

The functions of the project as stated in that act were: "to make basic studies of materials used in highways; to facilitate economical design, construction and maintenance of county and state highways; to investigate traffic, safety, and other items as desired and agreed upon; to provide advanced instruction in the fundamentals of highway engineering and related research; and to provide practical experience in construction and maintenance procedures and in the use of highway materials". Those are still, after 40 years, the functions of the Joint Highway Research Project.

Over the 40 years much research has been performed—well over 500 studies, and almost 1,000 students have studied and performed research in the program. The results of these research projects have been published in many technical publications, and copies of most of these are available for your information and use. Each year we report on some of our current research at the Purdue Road School.

The research conducted by the Joint Highway Research Project originates from several sources. One of the most important of these is from personnel of the state, county, and city highway departments who, through continuous contact with members of our staff, relay problems of highway planning, design, construction, operations, and maintenance. Other sources are national trends, policies, and activities of the several highway research and technical organizations which have the responsibility of enhancing technical knowledge in this area. Members of our staff are actively associated with each of these groups

and develop research potentially useful to Indiana and to the highway planning profession. Of course, there are also many other contacts, for a good idea in need of research, to make it useful to the profession, may come from almost any source.

This is the fundamental basis on which research projects are selected in the Joint Highway Research Project—will it add to knowledge pertinent to highway transportation in Indiana? We currently have about 30 active research projects and have completed about 10 during the past year. This paper will briefly review a number of these studies by first discussing the problem which caused each study to be initiated, briefly summarize how we attacked the problem, then tell you of results or expected results, and finally the benefits of application or use of these results. Let me start with one of our projects where the research results have been applied and where, as should be expected in first field experimental use, some problems and continued research is necessary. This project is our one on restroom facilities for interstate highway rest stops.

RESTROOM FACILITIES FOR INTERSTATE SYSTEM REST STOPS

Location of rest stops where they are needed for the convenience of the traveler are not always possible because of the inability to either obtain water or to dispose of the wastewater generated by the rest stop. Even where water is available and where discharge of treated wastewater can be accomplished, it is quite frequent that problems involving compliance with EPA wastewater discharge regulations are difficult to overcome. It is thus of great importance to interstate system development that answers to the questions involving water supply and wastewater disposal be developed which are not only cost effective, but which allow the facility to meet current and proposed EPA wastewater discharge regulations.

Numerous surveys of wastewater treatment facilities currently in use at rest stops throughout the country show that they have difficulty producing treated effluent on a constant basis which has less than 25 mg/l of suspended solids and BOD. In many cases, the systems fail to operate totally following prolonged periods of minimal use or following periods of adverse weather. The availability of water at rest stops is almost totally dependent upon ground water sources since the complexity of treating surface water is beyond the capability of a rest stop.

Ideally, the answer to the problem of both water supply and wastewater disposal can be minimized if the wastewater used for sanitary



Figure 1. At roadside rest areas, research on wastewater treatment to meet EPA discharge requirements includes experimental development of a system completely housed in the rest room facilities and re-use of water.

purposes can be recycled, and only the drinking and hand washing activities supplied with fresh water. As a second alternative, the problems of meeting an adequate discharge quality of treated wastewater can be achieved if a system operated on a filtration principle were possible and if that system could be miniaturized enough so that it could be housed within the rest room facilities.

The rest room facilities, established at the Thorntown rest park in the north bound lane of I-65, address themselves to the problem of producing a high quality effluent from a miniaturized system capable of producing an effluent satisfactory to the EPA, where the BOD and suspended solids in the effluent will consistently be less than 5 mg/l each. The facility established at the rest stop on the south bound lane has been designed to address the problem of minimizing water use by reuse of toilet flushing water and, in so doing, eliminating all need to discharge treated wastewater to a receiving stream.

The major benefits which are derived from the once-through-water-usage system in the northbound lane accrue from its ability to operate at peak performance whether it has been used daily or whether it has been used at infrequent intervals. This benefit cannot be measured in dollars but is measured in its ability to comply with EPA discharge regulations which cannot be done with any of the other current systems in use at rest stops when operated under highly divergent loading conditions.

The ability to house the system within a small facility, compared with conventional systems, and thus to be able to operate at uniform temperatures, instead of being at the mercy of the elements, is another important benefit which the system offers. From the standpoint of

costs and land requirements, the cost should be easily competitive with conventional systems after this prototype system has been fully developed and proven. Area wise, less land is needed for the rest stop because the wastewater treatment system is a minor factor for space and thus a definite reduction in dollars for less acres of land is possible.

The objectives for the rest room facilities on the southbound lane include the recycle of treated wastewater effluent. It has had more difficulties than originally anticipated. This system which approaches the ultimate in what might be done with a rest stop is receiving considerable attention to attempt to find out why it has not functioned as did the laboratory prototype system. Data to date indicate that for short periods of time it has worked well but long-term operation has been problematical and the reasons for the difficulties are not all known at present. Work is continuing and it is hoped that in the near future long term operation without problems can be achieved. If it is, the benefits will be substantial in thousands of gallons of water per day per rest stop, thus permitting rest facilities where substantial water is not available and where discharge of effluent is not possible.

The results of research, however, are the payoff and real payoff doesn't come until the results are applied. Recognition of this fact has always existed, but the increasing application of management science to governmental operations in recent years, emphasizes this requirement of research. Studies have shown that it often takes many years before a research result is applied. As a result, management is more and more looking for ways to diminish this time and giving greater emphasis to early application of results. This has been a major emphasis of the Federal Highway Administration in recent years, especially as application of results has been audited by oversight agencies of the federal government.

Unfortunately, the resulting federal regulations and application of these regulations by administering personnel have frequently resulted in an overreaction. As application of results from research is most easily documented where the research immediately results in a reduction in costs of doing something, federal management has tended to emphasize short-range research which can be so evaluated. Such research, of course, is valuable and should have high priority but management should never forget that much valuable research only results in new knowledge which when added to other knowledge, some of which may not be found for many years, provides the results which can be applied and which benefits one greatly. Some research, obviously will also not

be successful in meeting all desired objectives, but to say such research was not desirable fails to recognize the fact that knowledge of what will not work is one step toward finding what will work.

As a result of this management emphasis on application, this paper about our research, in this our 40th year, is structured towards application of results. As I noted, research results cannot always be applied by Indiana to lessen the costs of highway activity. Sometimes application will increase the costs but other benefits will result—more convenience and comfort for the motorist for which they are willing to pay, or greater safety, a characteristic of highway travel which all agree should be better, and it can be, but at a greater cost. For some research, the results cannot be applied to the highway system tomorrow or even next year, for additional new knowledge is still needed. But to conclude that the research did not have a substantial payoff is one that would be made only by individuals who believe in the “balance-sheet god” of the immediate dollar benefit. Wise men, on the other hand, have always counseled that real progress comes from increased knowledge.

IMPROVING EMBANKMENT DESIGN AND PERFORMANCE

Moving to another area of our research, one of the problems of building highways is concerned with the compaction of fill material in an embankment. What is desired, of course, is an embankment which will carry the pavement and the vehicles on it without deterioration due to failure of the embankment to supply the necessary load carrying requirements. The strength of the embankment is a function of its compaction, but the problem is what amount of compaction to specify. If more than necessary is specified, the cost will be unnecessarily high. If less, the support will be inadequate and pavement failure will occur.

The objective of our research in this area is to develop a technique for predicting the magnitude and variability of field behavior from compaction variables. Results to date include development of a nomograph which allows predicting what is the field as-compacted unconfined compressive strength and its variability if one knows the field dry density and water content and their variabilities from inspection control tests. Thus, once the suite of base data are established, we can define field behavior (without doing extensive strength testing) with increased confidence. Because these nomograms are statistically based, it appears reasonable to presume we could seriously examine how many

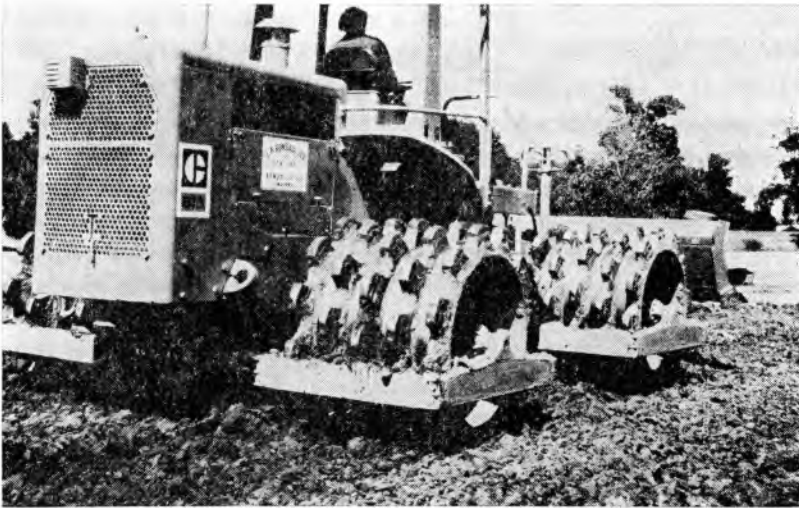


Figure 2. Research to develop a technique for predicting from compaction variables the magnitude and variability of field behavior has produced rational results.

inspection control tests are needed; perhaps their number can be reduced.

Again within the constraints noted above, another nomogram is available which links field as-compacted strength and its variability and the associated laboratory compaction data. This allows one to define a region on the array of laboratory compaction curves within which the field compaction is specified in order to produce a desired magnitude of field strength and a tolerable variability. This region then becomes the basis for the field inspection control tests.

With a more rational basis for specifying compaction, the designer can more readily perform parametric studies for his embankment. Different strength magnitudes require different geometric cross-sections, and each has its definable compaction costs. Thus, the search for optimum design is enhanced. It may be in some cases that the amount of compaction can be reduced without significance in the performance of the embankment—thus a benefit in less costs. In other cases, more compaction might be specified, with the benefit being a more stable embankment and lesser pavement deterioration.

STATE HIGHWAY FINANCE AND USER TAXATION IN INDIANA

Some research is always directed at policy issues, such as the one conducted this past year to provide information to our state legislators and to the public in the area of highway financing.

The rising cost of highway materials and decreasing fuel consumption, along with the changing social and environmental issues—all have a considerable impact on the financing of Indiana's highways, roads, and streets. While highway revenues have not changed significantly over the last few years, highway construction and maintenance costs have more than doubled. If the current trend is allowed to

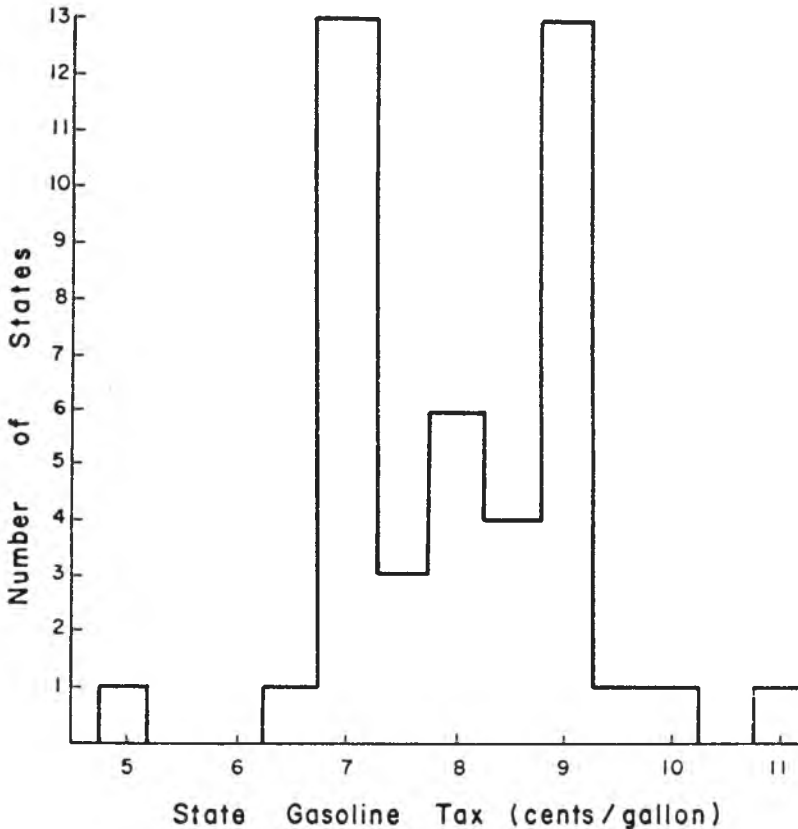


Figure 3. A major source of revenue is the gasoline tax. A survey of all states noted considerable variability in such state taxes with 19 states higher than Indiana.

continue, the gap between highway cost and revenue would become progressively wider.

The research included a review of highway cost allocation and taxation methodology, a summary of highway finance in Indiana, the results of a survey of highway finance in other states, and projections of highway revenue in Indiana under various policy alternatives.

The fuel tax and vehicle registration account for about 90% of the total user revenues in Indiana. While the average gasoline tax

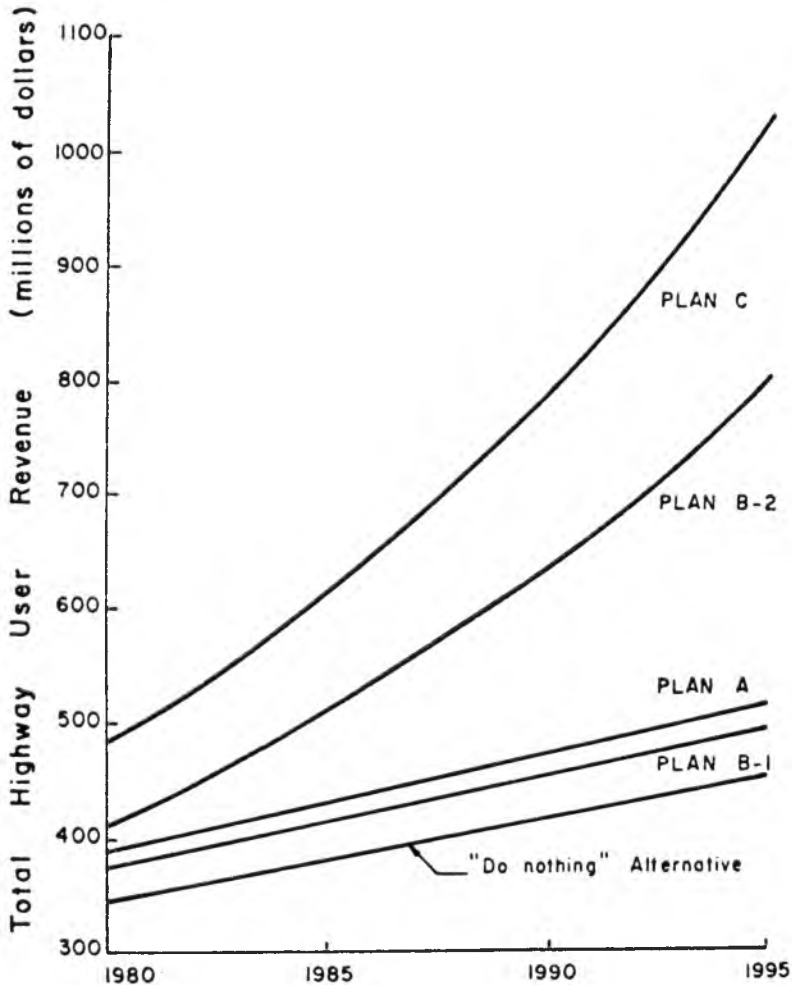


Figure 4. Several alternative plans for additional highway revenue in Indiana resulted from one research study.

rate is 8 cents per gal, a large number of states have a rate of 9 cents or higher.

It is also of interest to examine the last year in which a state raised its fuel tax rate. Fourteen states, or 30% of all the states surveyed, have raised their gasoline tax in the past three years. Over 20 states are currently considering increases.

Indiana's automobile registration fee is a flat fee of \$12 per year. It is not generally realized that Indiana has one of the smallest registration fees among the surrounding states.

Excluding Ohio, which imposes an additional fee on the basis of ton-miles, Indiana has the lowest motor truck registration fees among the six midwestern states of Illinois, Indiana, Kentucky, Michigan, Ohio, and Wisconsin. For a typical three-axle tractor truck Indiana charges \$285 compared to \$824 in Illinois, \$477 in Wisconsin, \$475 in Kentucky, and \$325 in Michigan. For a typical five-axle combination vehicle, the difference in registration fees between Illinois and Indiana is more than \$1,000.

A major finding of this research is that motor fuel tax could be indexed to inflation. This type of taxation, based on gasoline price and similar in nature to a sales tax, would automatically provide additional highway revenue as costs increased but without subjecting legislative bodies to frequent proposals for increased fuel taxation. At present nine states are seriously considering an ad valorem tax to replace the present per gallon tax structure. Several plans including such a tax were evaluated in the research.

The results of this research have been forwarded to the Transportation Advisory Commission and the roads committees of the Indiana State Legislature. It will provide important information for the state legislature in its decision regarding the type of highway user taxation to be followed in Indiana. That is its benefit—certainly not one which can be expressed in terms of dollars and cents but which may help contribute to more dollars and cents for highways in Indiana.

MAINTENANCE METHODS FOR CRC PAVEMENTS IN INDIANA

In the area of maintenance of highways, most of you are aware that we are involved in research on how best to maintain the several hundred miles of continuously reinforced concrete pavements constructed in the state and to provide answers as to why some of these pavements have deteriorated quite rapidly. Research projects on both problems were active this past year.

The extensive use of continuous reinforcement in concrete pavements is a relatively recent development in concrete pavement technology although they have been built experimentally since 1938. Concrete pavement design for highway pavements has gone through cyclic changes where the first pavements were poured without joints and they were unreinforced. The next step was to use relatively short slabs with preformed joints at spacings of about 10 to 15 ft. Later on, the joint spacing was increased to 40 to 90 ft—in Indiana the standard spacing of 40 ft between contraction joints was an accepted method of design.

One of the main problems dealing with this type of pavement was maintenance of joints. This problem brought about the use of continuously reinforced concrete pavements that have no joints, other than expansion joints at bridges and at other structures, and construction joints that are used at the end of a day's pour.

The use of continuously reinforced concrete pavements became widespread in the United States in the 1960's. In 1959, the U.S. Bureau of Public Roads issued a memorandum to the effect that CRC pavements meeting certain minimum design criteria would be approved for federal-aid projects. The use of CRC pavement in Indiana followed the national trend, and by 1971, almost 700 equivalent two-lane miles of CRCP had been constructed.

Performance of the continuously reinforced concrete pavements, however, was not up to expectations in Indiana and, by 1972, the distress to this type of pavement reached alarming proportions. It should be noted that this was true in many states of the country and was not peculiar to the conditions in Indiana, although the climatic conditions in this cold area have tended to aggravate the situation. By 1972, about one-third of the pavements were showing some form of distress.



Figure 5. Research on the best maintenance methods to repair deteriorating sections of continuously reinforced concrete pavements is concentrated in flat areas of Indiana where drainage is poor and subbase conditions are not the best.

When the Joint Highway Research Project initiated research in this area in 1972, it established a study wherein the reason for the large amount of distress could be detected and recommendations for new designs could be made. One of the first steps was to make a detailed study of the condition of I-65 in the vicinity of Lafayette. On the basis of this study, a state-wide performance survey was next set up, and as a third step, a detailed study of selected pavements was made. In conjunction with this, the fourth step involved a laboratory evaluation of materials.

The research suggested that one of the primary factors affecting performance of pavements was inadequate subbase, and in particular, high deflection and poor drainage of the pavement structure. Recommendations were made to the state relative to new design techniques that should be adopted, and these were in fact adopted by the state for several remaining contracts.

In light of the large amount of mileage of pavements in existence, however, it was also desirable to set up a research project to determine the best method of maintaining the pavements that are in existence at the present time.

A section of pavement which contained all of the known variables which affect performance of the type of pavement was selected. This pavement was a section of I-65 south of Indianapolis. First a detailed condition survey was made of the road, and second a deflection study was made. As a third step various maintenance techniques were constructed.

The section of highway studied is in a relatively flat area with poor drainage conditions where the pavement has an inadequate subbase. Various maintenance techniques were tried, including construction of concrete shoulders, installation of drains, undersealing, overlays, and various combinations of these.

As noted earlier, not all research results are positive, but negative results many times can be of extreme benefit to the researcher. In this particular case, it was definitely determined that several of the maintenance techniques were ineffective and too costly for the benefits derived. These included use of concrete shoulders without a keyway, installation of drains, and use of undersealing without an asphalt overlay.

This experiment is continuing and the severe winter we have just had should shed light on techniques that are effective in maintaining this type of pavement. Two methods seem to be practical; however, these should be considered to be tentative in nature since the final results

must await field surveys next fall. These include the use of concrete shoulders with a keyway and tie bars. Another effective method is to use asphalt overlays. An overlay by itself, however, may not be the most cost effective method of maintenance, since it is known that in many cases voids exist under the pavement. In all probability, the primary method of maintenance to be recommended will include deflection measurements to detect locations where there are voids under the pavement, undersealing where needed, and use of asphalt overlays.

Benefits in dollars and cents of this research would require the assumption that Indiana will build many more miles of continuously reinforced pavements. The earlier research did indicate how such pavements could be built to perform well. The findings increased costs of construction, however, perhaps to the point where such design would not be competitive with other designs. The current research also is finding techniques of how not to do such repair. Any calculated dollar saving requires assumptions of how they might have been repaired. Surely dollars will be saved, but the real benefit is that knowledge was obtained which now tells one better how to design such pavements and provides answers of how best to repair the inadequately performing pavements we have built. Those are two mighty important benefits.

IMPROVEMENT OF NONDURABLE AGGREGATES

Some of our research is directed at very old problems about which we know the causes but for which we still need to find less costly or practical solutions. One of these problems is the continuing D-cracking being experienced on some Indiana highways. This is caused by the use of nondurable aggregates in the concrete. Present test methods are not infallible in predicting such performance, especially for marginal aggregates. If a cheap method of treating marginal aggregates were available it would permit the use of many materials that cannot now be used safely, with a consequent great savings during the aggregate-short years certain to come.

Our approach is first to discover what kinds of pore systems in aggregates are responsible for difficulty. This is being done by mercury intrusion analysis coupled with more conventional tests on a large suite of about 20 aggregates from Indiana.

We anticipate that we will discover the details of the pore system that causes the failure. When this is known we will concentrate on methods to treat the aggregate so as to change the pore system to prevent failure.



Figure 6. Research on how to treat nondurable aggregates to prevent pavement deterioration is investigating the pore characteristics of aggregates which cause difficulties.

Such treatments would result in very great savings in the use of marginal materials. The study should also provide much better methods of deciding ahead of time on probable failure of these materials so their use could possibly be avoided and the consequent costs of repair and early resurfacing be saved. How beneficial will the research be? We will not know until the research is done and how successful we are in discovering methods of beneficially treating the aggregate. Many more years of research will be needed to reach a practical result. The benefits are potentially great. The research is really an investment in the probability it will be successful in obtaining those benefits. One certainly can place no dollar benefit on this study now or probably for a number of years, if ever. It may in fact cost more, but when durable aggregates are no longer available, there will be no other choice.

PREDICTING PAVEMENT PERFORMANCE USING TIME-DEPENDENT TRANSFER FUNCTIONS

Perhaps the major pavement problem facing highway engineers today is *not* how to design new pavements, but rather, it is how to evaluate, maintain, and upgrade existing pavement systems to optimize performance and minimize maintenance costs. Current pavement evaluation procedures are either destructive in nature or apply to only small

areas of the pavement. Add to this that the loadings are very different from those of actual vehicles and that they require considerable performance time.

One of our research studies reduced this problem to developing a method of pavement evaluation which would be able to quantify the stage of the aging process of a pavement and provide guidance with respect to its rehabilitation. The solution sought should be able to accommodate actual vehicular loadings under varying ambient conditions.

Previous studies with airfield pavements have indicated that there exists a unique relationship between pavement deflection with time (called an *output*) and aircraft loadings (input). The relationship is the "time-dependent transfer (TDT) function." In effect, the transfer function is a mathematical description of the mechanism whereby input energy is transformed into pavement deflections. The parameters (or descriptors) that scale the TDT function, in turn, provide a measure of "how well" a given section of pavement can transmit induced energy.

In the preliminary phase of the present study a number of linear variable differential transformer (LVDT) gauges were installed in a section of pavement near the campus of Purdue University. Testing was performed by passing trucks over the array and making deflection measurements at varying ambient conditions. Analysis of the test data

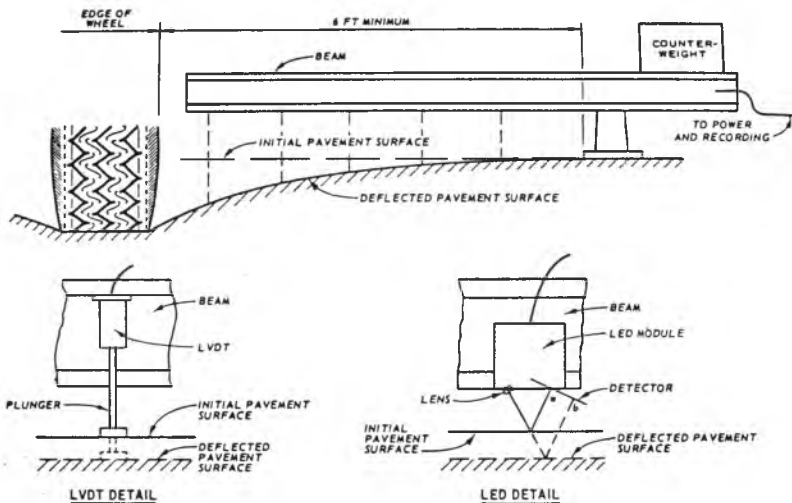


Figure 7. A mobile deflection measuring system for deflections of pavement, under wheel loads, shows promise of permitting rapid nondestructive evaluation of pavement performance.

indicated that transfer function theory was indeed valid for highway pavements.

The cost and inconvenience of using embedded LVDT gauges precipitated the development of an alternative deflection measuring system. Observations indicated that the width of the deflection basin extends less than four feet laterally from the outside edge of the wheel for highway pavements. This led to the construction of a portable aluminum cantilever beam which extended 5 ft from its support. Six LVDT gauges, fixed to the beam, were spring-loaded to make contact with the pavement. With the passage of a vehicle, the time-development of the deflection basin could be obtained. Combined with its ready portability, the device provided a nondestructive, rapid testing tool for evaluating highway pavements under actual vehicular loadings. Transfer function theory and characteristics of the deflection basin furnished the parameters that reflect the performance and condition of the pavement system.

Parameters of the TDT functions have been related to many current design parameters. Among these are the CBR, the modulus of subgrade reaction, and the stiffness modulus of the pavement. These measures are obtained in a non-destructive and rapid mode. Currently, such measures necessitate either test pits or cores or both. In addition to being expensive and disruptive of the normal flow of traffic, these procedures, of necessity, can only be used at a few locations. On the other hand, the LVDT beam is portable, rapid, and global, obtaining the measures under conditions of actual vehicle loadings.

Finally an evaluation procedure appears possible that can provide a measure of the number of years for which a pavement can be expected to perform adequately, a measure which would be most useful in the wise management and planning of highway maintenance.

BRIDGE VIBRATION STUDY

In the area of bridges, one might believe there surely is not much structural research still needed. We have been building bridges for many decades, and they usually outlive the pavements they serve or the decks on them. But the cost of bridges is great, and there are problems of vibration. All bridges, like any other structure, vibrate in the wind and to other loads placed upon them. In general, most human users of the bridge are not sensitive to such vibrations. Bridge design, however, is constrained by the need to keep vibrations of the bridge below levels of human sensitivity. But such restraints on design also preclude

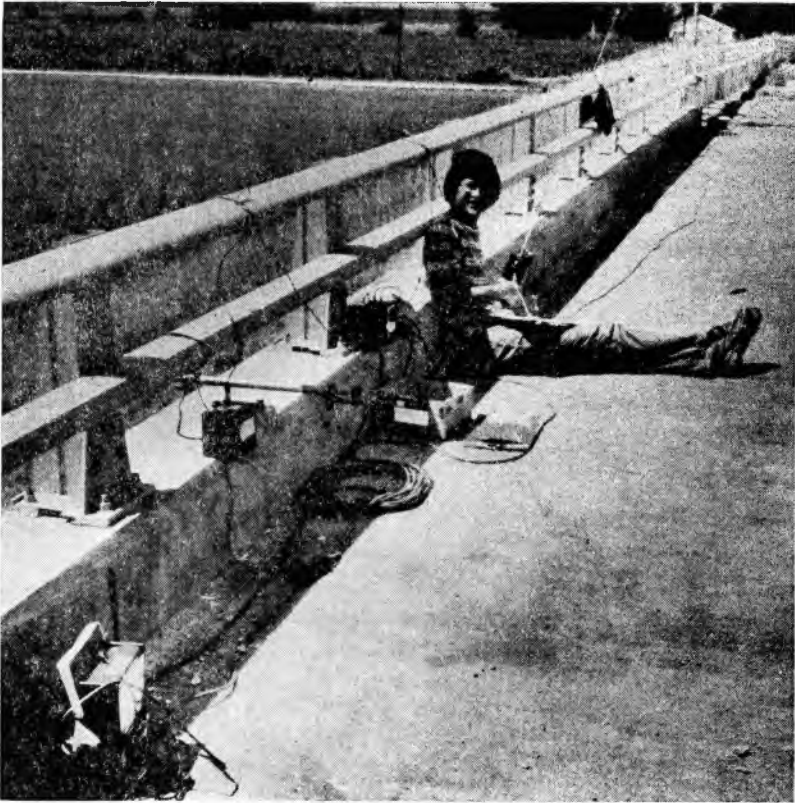


Figure 8. A study of bridge vibrations using much field data from a sample of Indiana bridges provides promise that designs can be made more economically and safely.

the use of some materials and designs which could decrease the costs of bridge construction.

We, therefore, initiated a study several years ago in the bridge vibration area. We evaluated vibration analytically and took many measurements in the field using sophisticated measuring devices, analyzing these data in our laboratories. In this study, as in several of our research activities, we worked cooperatively with the ISHC's Research and Training Center at McClure Park in West Lafayette.

Our analytical studies have shown significant parameters influencing bridge accelerations to be vehicle speed and weight, bridge span, and surface roughness. Maximum acceleration levels were found to be rather high for typical simple-span bridges; however for two- and three-span, continuous bridges accelerations exceeded the suggested comfort limit only when severe surface roughness effects were included.

Current specifications attempt to control bridge vibrations by limiting girder flexibility. For the bridges investigated in this study, only a small increase in maximum acceleration resulted when girder flexibility was increased by changing from A36 beams to smaller high-strength steel beams, thus more efficient high-strength steel designs may be possible without adversely affecting user comfort. Benefits from this knowledge are expected to be bridges constructed at less cost and use of resources and satisfactory user comfort. A prototype bridge is planned as an initial application step with more research on it before broad application of the results will be practical.

A LOW-COST MAINTENANCE PROGRAM FOR INDIANA ROADSIDES

Periodically, however, a research project does come along which results in benefits which can realistically be stated in dollar savings. Such a one is our study on a low-cost maintenance program for Indiana roadsides. This study, in fact, was a study of the effectiveness and benefits of the application of the results of a previous study at Purdue which, among other findings, concluded that weeds in grass turf could be most effectively controlled by a fall and spring application of certain chemicals once each three years.

With the development of the interstate system, the management of turfed roadsides has become an increasingly important function of the State Highway Department. Divided lanes, median strips, and broad rights-of-ways are an integral part of the design of the modern highway, and the management of turfed roadsides is no longer a minor consideration of roadside maintenance. The major economic losses due to roadside weeds can be traced to increased mowing costs (more mowing cycles are required due to fast-growing weeds rather than grass), weakening of turf, and shortening of the life of stabilized shoulders.

What happens when roadsides are not maintained in a turfed or semi-turfed condition? Even with careful landscaping and restricted mowing, areas which are not maintained will revert back to natural and native vegetation. Tall weeds and wild grasses will kill turf by shading, only to die back during the winter to leave patches of bare soil open to erosion. In as little as one year, our observations show that tree seedlings and root sprouts will become established on unmaintained rights-of-way and, after a number of years, the trees will add a hazardous condition to an otherwise safe highway. When this happens, the trees will have to be removed at considerable expense and the turf re-established to prevent additional erosion.



Figure 9. The problem of weeds and the large expanse of turfing areas required frequent and costly mowing.

In 1971, approximately 1,500 linear miles of highway received a fall application of 2,4-D between September 15 and October 15 under the spraying program by contract. Evaluations of test plots throughout the state showed the treatments to be extremely effective with weed control ranging from 85% to over 95%. Some roads previously unsprayed averaged over 500,000 weeds/mile before spraying. Because of the increased effectiveness of the fall-spraying program, one spraying cycle was eliminated from the contract program with an estimated annual cost saving of \$60,000 in the Herbicide Treatment Program by Contract alone. Yet this was only a beginning. These figures do not include increased weed control, reduced mowing costs, or the 30% reduction in spraying costs by district personnel as the recommendations were implemented at the district level. Research initiated under the

present project pointed to further cost savings in reduced mowing, so that an eventual annual cost savings in excess of \$800,000 is being realized. Further research to be implemented in 1977, leading to recommendations in scheduling remaining mowing cycles and in the elimination of one additional mowing cycle, will increase these cost savings by about \$300,000 to more than \$1,100,000 annually—over twice the total funds spent on highway research by the state at Purdue.

Other important benefits derived from the research include environmental safety. Herbicide treatments are scheduled principally in early spring and from September 1 until the first killing frost. In the early spring, roadside weeds are in their most susceptible stage while crops have not yet been planted and trees and shrubs are still dormant. In the fall, as the first killing frost approaches, hard-to-kill perennial weeds move all available materials into their underground parts and are most susceptible to the killing action of the herbicide. Yet in the fall, desirable plants in cropland and in roadside plantings have completed their growth and are either dying, dead, or dormant. Trees and shrubs are losing their leaves, and unlike the plants to be controlled, escape the herbicide. Problems of drift onto soybean or tomato fields are eliminated since the growing season is over. By the following spring, soil residues are completely dissipated especially with the bio-degradable herbicide 2,4-D. Only environmentally safe amine forms of the herbicide are used.



Figure 10. Use of environmentally safe chemical spraying virtually eliminated weeds and reduced mowing costs by over \$1 million per year in Indiana.

OTHER RESEARCH

Space will not permit me to detail others of our current research studies. The results of our Right-Turn-On-Red studies relative to when to prohibit the movement by installation of No-Turn-On-Red signs has essentially been adopted nationally as the standard for such prohibition. We quarterly perform for the state the federally required speed studies which indicate how well Indiana motorists are obeying the 55 mph speed limit. The recently completed bridge deck study has resulted is several bridges built or the deck replaced in similar fashion in Indiana, Illinois, New York, and possibly other states. The ISHC plans to begin using nuclear density gages for control of portland cement concrete consolidation. Research on such use is now being completed at Purdue. Research is continuing, but initial results are being utilized from our study on design and construction guidelines for shale embankments. A testing procedure was developed on another project which will lead to better performance of asphalt emulsion bases and significant costs in maintenance requirements. And there are others, including a new bluegrass for roadsides.

CONCLUSION

Forty years of research has not dulled our belief that the conduct of research and its application results in tremendous benefits. Perhaps,



Figure 11. One research project developed a precast, prestressed bridge deck which can replace a deteriorated deck in a very short period of time, thus saving much inconvenience and economic damage to area residents.

however, the examples I have reviewed are not convincing. As a final argument then, let me note that highways are certainly better today than ever before in history; they give more comfortable use before deteriorating, and they are safer. This did not all occur because of more funds to build better highways or because we became more knowledgeable through experience, although both of these are important factors. Much of this progress has been the result of research which produced knowledge which was then applied to the planning, design, construction, operation, and maintenance of highways.

I have reviewed some examples of such new knowledge from current research activities at Purdue, performed in cooperation with the Indiana State Highway Commission and considerable of it in cooperation with the Federal Highway Administration. But one can think of much more. Whatever the task is for which you have responsibility, you can be sure the present best way of doing it probably developed from research performed somewhere by someone and then applied by someone else with experience. There probably today is some knowledge available from research somewhere which would make the task you have even easier, cheaper, or the results better. Part of your job is to seek such knowledge and apply it. That, of course, is the major reason for the Road School. The researcher also has a responsibility to see that the new knowledge is made known and applied, but that responsibility is not his alone. It lies with every professional person involved with transportation.